Questions on valuation of Natural Capital: evidence from Canada 1970-2011

Ezechiel Kahn under the supervision of Professor Thomas Piketty

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Abstract The thesis begins by getting interested into the different ways past literature tackled nature definition and valuation issues, to question and attempt to complete this definition for the inherent unknown component of natural capital in opposition to manufactured capital. The following study, addressing Canadian natural wealth and wealth-income ratios has the purpose of comparing two viewpoints, 'ex ante' and 'ex post' defined in section 3 to justify the previous adaptation of the definition of natural capital, and to support both caution in valuation methods of natural assets and precautionary polices. I adapt the wealth-income ratios of Piketty-Zucman (2014) to include natural wealth in Canada. I find the market value of the ex post stock has declined from more than 750% of national income in 1970 to about 360% in 2012. Out of this 40% decline, about 35 points can be attributed to a volume effect (i.e. about 35% of Canadian natural resources were consumed and/or depleted in the past 40 years) and about 8 points to a price effect (i.e. the price of natural resources has increased relative to GDP price of index, by about 3.8% per year on average between 1970 and 2011, but less than the real GDP growth rate of the period, i.e. 4% per year).

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Abbreviations

- SNA: System of National Accounts
- GDP: Gross Domestic Product
- NDP: Net Domestic Product
- ANDP: Adjusted Net Domestic Product

1 Introduction

The value of wealth is an important index of economic efficiency, as it testifies on the capacity to generate future incomes. The national wealth of a country is often considered as being equal to the value of its manufactured goods it owns, such as facilities, machinery, commercial lands, agricultural lands, inhabited lands. However a broader and more general way to consider national wealth is to take into account the important impact of natural assets on the economy and society. To that extent, its impact can be evaluated by a census of natural resources stocks and ecosystem and by the addition the obtained values to national wealth.

However, doing this exercise requires to be conscious of the meaning, the benefits, and the drawbacks of putting a value or a price on natural capital and more generally on nature. As incorporating nature in economy seems to require at first sight to translate the value of nature, which can be recorded in different physical units or even descriptions depending of the considered asset, into a price, a price evolution does not give all the information needed to have a full understanding of the evolution of natural stocks. Indeed, a rising price can be due for instance to a volume or a price effect.

Moreover, the reason why to put a price on nature has an important impact on the way one should do it. If it is just to value how nature is valued nowadays in markets, there is not much work left to do, as non-valued assets could be considered as having a value of zero. If we try to reach a deeper understanding of, even if the services of nature seems to be free, what value they bring to human activities, it is a different story, and brings us to look at the changes in time of these services. If human activity tends to destroy nature in such a way that we loose more benefits from nature than we gain by our production, it is important to be conscious of it and to try to modify it as we would be heading backwards and cutting of the branch we are sitting on without even noticing it. Of course we have some evidence and warning from nature such as global warming, pollution spikes, ice melting but this is not exactly the same question. Global warming means that our way of living, our activities, our production are not adequate with the global ecological balance of our planet Earth. The question I am raising is different but has that previous observation as a possible consequence. The question is "Are our activities as a whole enhancing global welfare and is our production really efficient considering the losses on the nature's side of economy? ". Of course I will not pretend to answer the question here, but I will try to point out some interesting facts that could help us have a better understanding of the question and its actuality.

In this work, I first add a fourth difference between natural and manufactured capital to the three Edward B. Barbier stated in [1] which is that nature is by essence unknown and that it is an important fact to take into account when trying to incorporate it into the valuation of an economy. Secondly I introduce the notions of valuation of natural capital 'ex post' and 'ex ante', two different point of views from which natural capital can be measured (with the knowledge of the time of the measure vs. with today's knowledge). I use them to bring to light the importance of the fourth difference I stated previously, which gives all relevance to precautionary policies and brings more caution to the way one can put a value on nature. Doing so, I document the evolution of wealth-income ratios in Canada taking into account natural capital and the decomposition of natural wealth between 1970 and 2013 or less depending of the data available.

The thesis will begin by locating the work in the past literature to better understand what is considered as given and what are the specificities of this work. Then will be defined according to [1] and others before the fundamental differences between natural capital and manufactured capital, and I justify the addition of on more. In section 4, I present the different ways to value natural wealth in the literature and what it brings to the issues I raised. In section 5, I emphasize the consequences of differences between the two viewpoints 'ex ante' and 'ex post' in the data and what we can conclude from them. In section 6 I detail the databases I worked with, how they are built and how to place them in the conceptual definitions of sections 3 and 4. In section 7 I expose the composition and dynamics of natural capital in Canada and use the results two tackle the issues I raised before. In section 8 I show the evolution and dynamics of Canada's wealth-income ratios with and without taking into account natural capital. In section 9 I stress the example of the distinction between two ways of valuing timber and forests and how it serves my argumentation. Section 10 concludes.

2 Relationship to literature

The subjects addresses several types of literature. In addition to all the natural sciences which brings a deeper knowledge of natural processes and functions, there is space in this question for literature on environmental economics (and on valuation of natural capital), national wealth and capital accumulation and growth.

In Capital is Back: Wealth-Income Ratios in Rich Countries 1700-2010 (2014) [2], Thomas Piketty and Gabriel Zucman address a very essential economic question: "how do wealth-income ratios evolve in the long run and why?" This article, use 1970-2010 national balance sheets of eight developed economies, the United-States, United-Kingdom, Germany, Canada, Australia, Japan, Italy and France and for four of them on the very long run, as far back as 1700. They found in every country a rise of wealth-income ratios in recent decades from around 200-300% in 1970 to 400-600% in 2010, ratios appearing to be returning to the high values observed in Europe in the eighteenth and nineteenth century. The authors used for their work the conventions of the SNA93, System of National

Accounts version 1993. They incorporated in this work the value of lands but no other natural asset.

In this master thesis, I try to shed a new light on these ratios by taking into account in different ways the natural capital. This change has both an impact on adjusted net national income which is national income adjusted for the depletion of nature and on wealth which here takes into account on the top of what considered T. Piketty and G. Zucman in [2] the natural capital.

In Natural Capital and Wealth in the 21st Century (2016), Edward B. Barbier already adapted some of the results of Capital is Back [2]. He first adapted their one-good wealth accumulation model to allow for natural capital depreciation. Including net depreciation in fossil fuels, minerals and forests produces then two indicators: the net national saving rate adjusted for natural capital depreciation s^*, and the ratio of this rate to long-run growth. He uses the data from the World Bank to observe the evolution of these two indicators for a set of countries.

The literature on valuation of natural capital was very interesting and inspiring in this work, beginning with Wealth Accounting, Ecological Capital and Ecosystem Services(2013) from Edward B. Barbier [1] again and a lot of sources of the article itself such as [10] or [14]. Barbier in his article raises the issues of how to define natural capital in opposition to manufactured capital or human capital, and gives a method to quantify it with his famous example of valuation of mangroves in Thailand.

Part I
Conceptual issues about Natural Capital

Our economic system is by definition interacting with nature by several ways: nature provides us with energy (solar energy, oil, natural gas, wind...), with goods (food, timber, minerals...), with services (stable and livable environment, protection, pollination, water purification...), and life-fulfilling conditions (such as beauty and serenity). Whereas some of these benefits we have from nature are in a way taken into account in the economy and even industrialized by human activity, such as agriculture, it is a recent trend to try to incorporate nature as assets in the economic models. Global warming for example leads us to get more and more interested in the interactions between the economic system and the ecological system which could be considered (or not) together as only one system. A step forward could be to try to value natural wealth as assets and look how it transforms the way we see national wealth.

The standard indicator of economic progress is real per capita gross domestic product (GDP), the market value of all final goods and services produced in an economy. One of the problems with this indicator is that it does not reflect for instance the degradation of the underneath natural capital such as wood, minerals or energy used for the production of goods and services whereas for these productions, stock of natural assets were depleted. It is all the more striking that the stakes of recycling are high, and the second principle of thermodynamics adds an irreversible component to our reflection: a part of the natural assets that are used are really degraded and lost, and are a loss for who ever was the owner of the asset. It thus does seems relevant to introduce a net of natural capital depreciation index as E. B. Barbier write about in Wealth accounting, ecological capital and ecosystem services [1]: the adjusted net domestic product of a country. It would give a better estimation of what is truly added to the economy's total capital or wealth. As E. B. Barbier explains it in his article [1], it has been demonstrated that economic development is sustained if and only if total investment in wealth is non-negative over any time period. This idea of deducting any capital depreciation, such as natural capital depreciation, from GDP to obtain a "net" index was already pointed out by Lindhal [13] that in a sustainable economy, investment should exceed consumption, even consumption of existing capital. If it is not the case, the GDP can reach values that are not representative of the state of an economy in for example a period of recovering from a massive catastrophy. For instance, in Japan, the Fukushima incident did not affect the national GDP as much as it has destabilized the local economy and destroyed an important part of national wealth. It can even had been increased by the reconstruction efforts.

As recorded by Barbier, a growing literature has demonstrated that any system of net domestic product accounts should be extended to include two other economic assets: human and natural capital. We get interested here into the second one.

The need or will to integrate the natural capital to global indices demands several adaptations. First, to define precisely the limits of the concept of natural capital. Second, when it is defined, to find a satisfying way to value natural capital. Third, but not independent from the first steps, to, as capital is currently valued by country and the difference is made between private and public wealth, identify the property rights and whose wealth is the natural wealth.

3 Definition and specificities of natural capital

In his article Nature in economics (2008) [14], Dasgupta reminds that ecosystems differ from reproducible capital in three ways:

1. depreciation of natural capital is frequently irreversible (or at best the systems take a long time to recover)
2. except in a very limited sense, it is not possible to replace a depleted or degraded ecosystem with a new one
3. ecosystems can collapse abruptly, without much prior warning.

The main distinction between the first and the second difference is that the first one discusses the fact that an ecosystem cannot be repaired whereas the second one expresses the fact that it is difficult to build a new equivalent ecosystem to replace a destroyed one.

One of the point of this master thesis is the introduction of what I think to be a fourth very important difference between natural and manufactured capital. By definition, manufactured goods are made to answer to a need or a mission and thus are understood and valued for the need they answer to. In opposition, natural capital is, as there is still a lot of work for natural scientists, by essence very badly known and understood (relatively of course). It is thus very difficult to define the limits of the impact of a given natural object, and all the more difficult to put a moral or a dollar value on it.

To explain my point I will stress the example of bees. If at a first glance they could just seem in comparison with global human activity as a trivial detail of nature, we discovered that we were in fact totally dependant on their activity to survive, and thus in a way they support the totality of human activities which would not exist without them. However, this scientific discovery had not been made, human activity could have threaten this very species whose value would have been considered near zero whereas it is in fact decisive and crucial. Even being conscious of their importance, their fate remains uncertain.

Another example is the recent discovery of the tasmanian devil female's milk properties in October 2016. The marsupial's milk contains important peptides that appear to be able to kill hard-to-treat infections, including MRSA (Methicillin-resistant Staphylococcus aureus), say a Sydney University team. As the species was on the way of extinction, we could infer that a reason could be that the intrinsic value of the marsupial, if one would had been put on it, would had been low, and would have change upwards at the date of the scientific discovery. However, the property of the milk had always been there even if we did not know about it yet, so the real value of the marsupial did not really change at the time of the discovery.

We can thus, when we look at the fictive value of the animal consider that it increased last October or that it has always been there, we just did not know. So when we look at the depreciation of natural capital due to the disappearance of the tasmanian devil, we can consider first that we suffered a large depreciation of natural capital threatening such a discovery to not exist or that on the contrary as we did not know the property yet, depreciation was not important and we even gained wealth at the date of the discovery.

The distinction between the two viewpoints is exactly the same as considering at the discovery of new reserves of oil that it is an addition to the past stocks or just a translation of the past stock upwards without any change in the trend, as it is illustrated with fictive oil stocks and a discovery of one unit of oil in 1990. Changing of viewpoint changes the entire dynamic of wealth. The two point of views have different meanings, the first one, considers only what we know at the moment of the measure whereas the second one, considers all we know today (2015 in the figure) as known in the graph.

Generalizing it, we can see the value of natural capital from two points of view that I will define as ex ante and ex post. The 'ex ante' viewpoint means that you consider that each discovery we make did not exist in the past, and thus is translated by a change only beginning at the date of the discovery of the value of the asset whereas the 'ex post' viewpoint would consider that even if the discovery was at date t, it existed before and that changes the way we look at the past.

The strengh of this distinction is that it directly illustrates the different ways of looking at the changes of wealth as the 'ex ante' viewpoint gives us the wealth we thought we had at the considered time whereas the 'ex post' viewpoint gives us the wealth at a the same time but knowing all of what we know at the time of the computation and visualization of the data: today. It thus gives different and a probably deeper understanding of the impact of our behaviour on global wealth. It does not make the 'ex ante' viewpoint obsolete at all as it simply

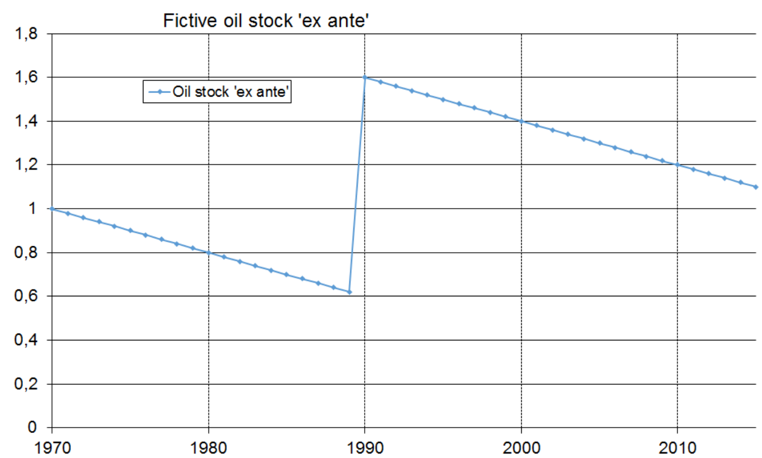

Figure 1: Fictive Oil stock with a discovery of 1 unit in 1990 'ex ante'

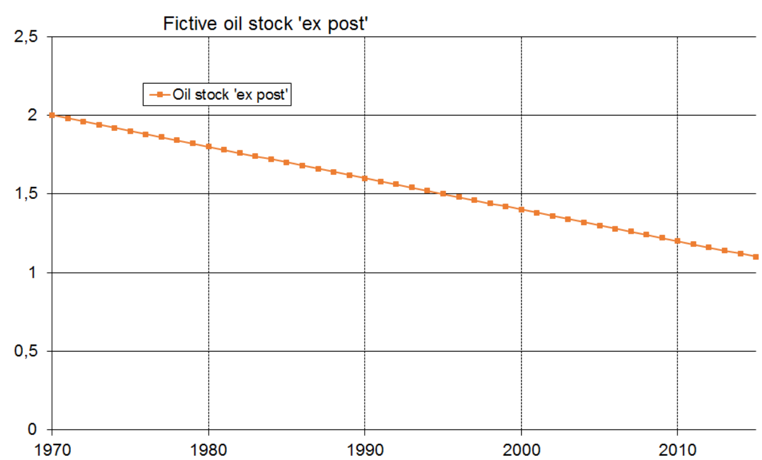

Figure 2: Fictive Oil stock with a discovery of 1 unit in 1990 'ex post'

tells different stories, as their comparison and their differences shed light on the fourth specificity of natural capital I raised previously: we know more later.

To the best of my knowledge, this kind of distinction was never made before.

Each of these four differences have an impact on, if natural capital should be valued in monetary terms, how this valuation should be done.

4 Valuation

4.1 Physical valuation

The first method of valuation, being also the first step of the other ways of valuation I will write about is physical accounting. It means having an account for each species or type of natural asset recorded with physical units. For instance, hectares or volume for forests, tons or weight for minerals, volume for water, weight, volume or even energy equivalents such as joules for oil or natural gas. This is an interesting method as studying the evolution of the stocks of a natural asset in physical units gives straightforwardly information about the variation of stocks and its consumption/depletion, which is not the case with a monetary value where it is harder to separate the price effects from the volume effects.

It is interesting to remark that the distinction 'ex ante'/'ex post" also has an impact on these values for energy as depending on the time of reference and the technological development associated with it, the amount of energy able to be extracted from natural gas is not the same. The viewpoints distinction allows indeed to have a critical point of view on valuation methods as we would like, when assessing a value of something, for it to be the nearest of its "true value". If we assume that the more time goes, the closer we are to understanding the value of nature (probably without never seizing it completely), a valuation 'ex post' is closer to the "true value" than the 'ex ante' one as it is made with more knowledge. It is true for scientific discoveries as for discoveries of new stocks. Having the two viewpoints values very close would thus mean either that we had not discovered a lot of things between the two dates or that the way of putting a price on the natural asset took relatively well into account the fact that there were still a lot of unknown parameters in nature, and it is what we would like to finally get to: a better way to value nature.

The physical accounting can and should be coupled with all the attributes of each assets which can allow to have a better understanding of each type of natural capital, the services it provides to human or to global balance, directly or indirectly. These attributes are also function of the current scientific knowledge at disposition on the different natural assets.

Several issues appear if we just content ourselves with this physical accounting method. Indeed, if we can for example look at natural gas and oil from the same point of view of the energy they can provide, it is difficult for the vast majority of assets to have an aggregate index of how natural resources stocks behave as a whole as we cannot add apples and oranges. We evolve with this accounting method in a space of a dimension as large as the number of type of assets taken into account in the census and it is thus difficult to reach a clear understanding of the dynamics of the stocks globally.

Moreover, if it allows to keep an eye on the evolution of each of our environmental resources, it does not discriminate which asset seems to have a more important impact or is more essential to human activity than the other (as we value it from a human point of view). If it is not a goal to put a hierarchy on nature, it is still interesting to have a better idea and a comparative tool to reach more informed decisions, for example in business or in politics, where it is important to be able to compare different possible alternatives.

A logical common unit which could answer to these problems of valuation is money.

4.2 Monetary valuation

4.2.1 Market Price

It is the first and more "direct" way to put a price on assets, which should be a first approximation of the value as it is answers to the law of supply and demand. However, if subsoil assets and energy are directly used by firms and thus the market is already existing, it is not the case for the large majority of natural assets. Moreover, some of the values can be artificial as controlled by groups such as OPEP for oil, and thus does not follow the law of supply of demand and gives a different piece of information.

Different possibilities will be described in the fifth section of the thesis, especially in the directives given by the SNA [4, 5] and by [9].

Nevertheless, market prices often do not reflect the social cost of production and moreover most natural services are not presently traded on markets.

4.2.2 Valuing services of nature as the price of the services they provide

This method of valuation was described in detail in Wealth accounting, ecological capital and ecosystem services written by E. Barbier [1]. His accounting framework leads to the following three main contributions:

- Accounting for ecosystems and their services leads to adjusting NDP (net domestic product) for direct benefits provided by the current stock of ecosystems.
- NDP should reflect the irreversible conversion of natural capital to other land uses.
- As ecosystems are likely to collapse, the benefits of ecosystem should be weighted by the probability of the ecosystem surviving.

These three contributions take into account the three differences between ecological and manufactured capitals. Taking into account the fourth difference I wrote about could be made by considering this pricing method as a lower bound of what the value of the asset could be, or more broadly on a different way to interpret the results of this or any other accounting framework.

Barbier classifies the benefits from ecosystems in three categories:

- Goods (production obtained from ecosystems, such as water, harvest...)
- Services (recreational and tourism, climate regulation, habitat provision, water purification...)
- Cultural benefits (spiritual and religious beliefs, heritage values...)

Some of these benefits could be qualified as direct as they contribute directly to human welfare such as enjoyment of the environment or reducing harmful pollution and indirect as they contribute indirectly to human welfare such as protecting activities, raw materials... The distinction between direct and indirect benefits have its importance for adjusting NDP which should only be adjusted for the direct benefits but not for the indirect contributions as they are already in a way taken into account in the NDP. This double counting issue does not occur for wealth accounting.

Barbier shows a way of adjusting GDP for services of ecosystems, but a discounted value of these services could thus put a value on the corresponding stock of assets.

Barbier in his article illustrates his theory and his accounting framework with the example of mangroves in Thailand over the period 1970-2009.To do so, he starts by stating four direct benefits provided by mangroves:

- Storm protection:based on marginal value of damages avoided
- Habitat for offshore fisheries: based on fishes prices
- Carbon storage: based on the capacity of carbon sequestration and the estimation of the damage of a unit of carbon at US$20 per ton by the World Bank
- Wood: based on related income of the local communities

He valued the services the following way :”

- the value of coastal protection from storms is based on a marginal value per ha of damages avoided (in 1996 US$)of US$1,879; over a 20-year time horizon and a 10 per cent discount rate this yields a net present value (NPV) of US$15,997 per ha.

- The value of habitat–fishery linkages is based on a net value per ha (in 1996 US$, assuming a price elasticity for fish of 0.5) of mangrove habitat of US$249; over a 20-year time horizon and a 10 per cent discount rate this yields a NPV of US$2,117 per ha

- The value of wood and non-wood products is based on net income per ha from mangrove forests to the local community (updated to 1996 US$) of US$101; over a 20-year time horizon and a 10 per cent discount rate this yields a NPV of US$864 per ha

- Chmura et al. (2003) [12] permanent carbon sequestration by global mangroves of 2.1 metric tons per ha per year, and World Bank (2011)[7] values unit CO2 damage at US$20 per ton of carbon (1995 US$), which yields an annual value (in 1995 US$) of US$42 per ha for carbon sequestration. Over a 20-year time horizon and a 10 per cent discount rate this yields a NPV of US$413 per ha."

On a whole, he estimated the current benefits of mangroves in Thailand converted in 2000US$ value of US$2,519 per ha, and a capitalized value of US$21,443.

On the other side, still according to Barbier, the main activity for mangrove conversion in Thailand has been shrimp aquaculture which net present value per ha over a 20-years time horizon and 10 per cent discount rate is US$1,351 per ha in 2000$ which is inferior to the one of mangroves. Such a comparison should then make decision-takers more likely to defend mangroves. However the ' ex ante'/'ex post' distinction has also its importance here, as as this valuation was not known before, people thought that shrimp farming was more profitable than mangroves and destroyed them, without assuming that there could have been an unknown value that they did not take into account.

Figure 3 shows that as they did not know the current 'ex post' known value of mangroves, the population of mangroves was destroyed on the benefit of shrimp farming. Barbier explains in his article that "the principal reason for the slowdown in mangrove loss is that many of the suitable sites for establishing shrimp farms in the Gulf of Thailand have been deforested, whereas the mangrove areas on the Andaman Sea (Indian Ocean) coast are too remote and less suitable for shrimp farms". The slowdown is thus not due to the learning of the benefits mangroves provide.

However, it is still difficult to put a price of the satisfaction derived from contemplating a tropical rainforest, so some services are easier to value than others.

4.2.3 Valuing services of nature as the current cost of the technology allowing to provide an equivalent service

This method is referred in [10] as the avoidance of costs, for example valuing natural water purification service at the cost of its technological alternative, as

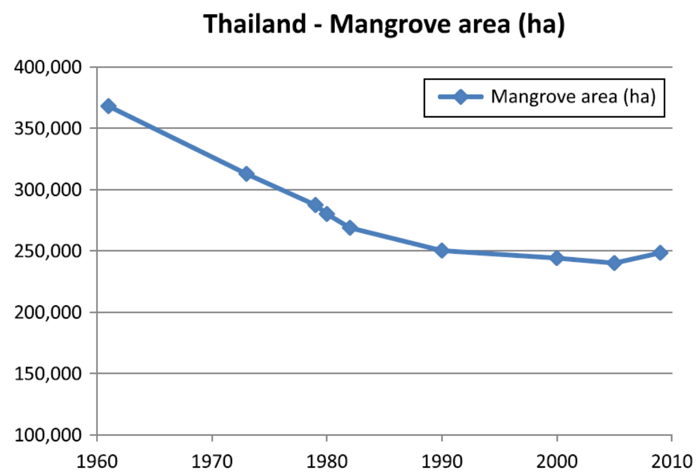

Figure 1. *Estimated mangrove area, Thailand, 1961–2009*
Source: FAO (2007*b*) *and* Spalding *et al.* (2010).

Figure 3: Mangroves Area from [1]

a filtration plant.

The idea is parallel to the previous method, but instead of using the price of the service, the price of a technological substitute is used.

The first hindrance to that method is stated in [10]: the fact that each service does not have today a technological substitute, such as climate regulation.

4.2.4 Contingent valuation

It is a traditional approach to quantifying externalities. The idea is to ask people directly about their the value they attribute to different assets. It thus uses stated preferences. This method is interesting but suffers a lot of drawbacks. Moreover, there are a lot of limitations stressed by for instance Diamond and Haussman , 1994 [11]: the cost of designing and conducting the surveys (for each asset), the framing effects (for instance people give different values if they are asked first to put a value on whales then seals or on seals then whales), "embedding" effects (for instance the willingness to pay to clean one lake is going to be equal to the willingness to clean five lakes) and finally people can answer strategically rather than giving the actual value they think is right.

Moreover, a lot of natural assets require an understanding too deep for people to put a reliable value on it, especially when we recall the fourth difference between natural capital and classic capital.

4.2.5 Hedonic valuation

This method also used to quantify externalities uses revealed preferences for estimating the value of a good by studying market with and without the considered asset (for instance the impact of a forest on the housing market prices). It can be used to estimate economic benefits or costs associated with: environmental quality, including air pollution, water pollution, or noise environmental amenities, such as aesthetic views or proximity to recreational sites, which could complete the second method I wrote about and developed by Barbier [1] of valuing services provided by natural assets.

4.2.6 Price of replacement

The price of replacement is the simple principle that the price of the tree is the price of planting a new one and waiting for it to be on the same size and health of the previous one. This price can less be used on assessing the price of a whole stock of assets whereas it would unreadable or only on a logarithmic scale as increasing an already big population of animals for instance seems to be quite easy and cheap whereas the last rhinoceros couple's price will be infinite as if it cannot be replaced after its destruction. It would thus be only an interesting tool for the ecological impact of business decisions such as deforestation to build a road, what is the price to recreate or replace the destroyed ecosystem?

A strong point of this method is that it solves (in a way, not perfectly as replacing a depleted ecosystem is very difficult" the 'ex ante/ex post problem' of unknown of nature as it implies not to disturb it too much or the price will be too high. This price can be weighted by the probability of the ecosystem to collapse as it is hinted in Barbier's article [1].

Conclusion of Part I and transition to Part II We understood that taking into account natural flows (benefits or depletion) and stocks into economic indicators give a better intuition of the dynamics of an economy's wealth. However we raised the issues coming with trying to value nature in monetary terms, especially under the light of the fourth difference between manufactured capital and natural capital: the fact that we do not know nature. This remark gives full sense and relevance to the implementation of precaution principles to regulate global activity.

In the core of these considerations of valuation and unknown is the opposition between the two viewpoints 'ex ante' and 'ex post'. Indeed, if differences are observed between those two, it validates the importance of the fourth distinction between the two broad types of capitals and thus gives limitation on the very principle of putting a price on nature.

Part II
Experimental evidence: Canada from 1970 to 2013

For the size of the natural resources and quality of the data reasons, I chose to center the study around the case of Canada. There are indeed available on a long period of time (mostly from 1961 to 2014, depending on the resource) and the additions and depletions of the stocks are detailed. However, although it is interesting to visualize the dynamics of natural and total wealth of any country, focusing on only one already allows to tackle some of the questions I raised in the first chapter of this thesis. Indeed, there is no need of more than one country to get interested into the order of magnitude of the natural capital and see how taking it into account can change how we see the dynamics of national wealth. More specifically, there is no need of more than one country to stress and understand the signification of the differences between the 'ex ante" and the 'ex post' viewpoints, and to learn the lessons it gives independently from the country.

5 The interpretations of 'ex ante' and 'ex post'

I insisted a lot on the distinction between the two viewpoints and it is thus important, after having defined them in the previous chapter, to be precise on the signification of them, and on how to interpret data under each of them.

On the one hand, data observed 'ex ante' at time t is the data as observed by someone having just the information available at t. It thus gives the dynamics from the point of view of someone who has just the information available at time t at each measure. On the other hand, data observed 'ex post' at time t is the data at time t observed with all the complement of information available at the present time (most recent data, often 2014). It thus gives a step back on the "real" evolution of the data observed with all the information that had been gathered from date t to 2014.

The first example which make the distinction between the two of the is the discoveries. The stocks of resources 'ex ante' can grow as new discoveries are made whereas from the 'ex post' point of view, we consider all the discoveries already made as the resources discovered from then were unknown but actually existed. Thus, the "ex post" viewpoint gives an idea of what really happened if we consider everything we know.

If we wanted to express the difference in mathematical terms, observing a value $A(t)$, function of time, 'ex ante', is plotting $\mathbb{E}[A(t) \mid t]$ as a function of time t whereas observing it ' ex post' from date T is plotting $\mathbb{E}[A(t) \mid T]$ as a function of t, where T is in our studies the present or latest data available, often 2014.

Practically, in the large majority of the computations I made, I solely used market values of industrialized resources such as energy (coal, oil, gas) or minerals. My reflection is that if the way we see national wealth or even natural wealth is already transformed when we change from a viewpoint to another, it will be all the more so striking if we value and take into account other resources or natural assets that are not directly on the market, or use different methods of valuations detailed in section 4. Indeed, if the dynamics of the stocks of oil 'ex ante' and 'ex post' are significantly different whereas it is a resource that is frequently studied, valued, and used and thus assumed to be well understood and managed by the industries using it, I assumed the difference will be greater for resources that are less carefully managed such as forests, air pollution, corals etc. A significant difference between the two viewpoints would thus give full importance to tacking into account the fourth difference between natural capital and manufactured capital in all activities, for instance by respecting precaution principles.

6 The Data

Before treating the data, it is already interesting to know how it is measured and managed to understand at what point the countries globally are on taking into account the natural capital in their aggregate accounts. First, in this sens, I will detail the natural capital related instructions of the SNA (System of National Accounts), which "is the internationally agreed standard set of recommendations on how to compile measures of economic activity. The SNA describes a coherent, consistent and integrated set of macroeconomic accounts in the context of a set of internationally agreed concepts, definitions, classifications and accounting rules." [4].

6.1 The SNA93 and SNA08

The SNA defines economic assets as "entities over which ownership rights are enforced by institutional units and from which economic benefits may be derived by their owner." As pointed out in [2]'s Appendix, because ownership rights cannot be enforced on human beings, this definition excludes human capital. As a consequence education and health services are not treated as investments but as consumption.

Before getting involved in how to value natural wealth, it is interesting for the sake of comparison to remind that there are four broad ways to measure national wealth, the first two being the most used

1. by taking a census of wealth
2. by cumulating investment or saving flows with adjustments made for depreciation and changes in prices, known as the perpetual inventory method
3. by taking the discounted value of the future economic benefits of the capital considered.
4. by taking the asset values reported by insurance companies.

Regarding the Natural Capital, the perpetual inventory method is useless. But a way to measure is is for instance using the first quoted method, taking a census of wealth. We will detail later the different ways to measure, quantify and monetize natural wealth in a subsection devoted to that.

The SNA treats the non-produced tangible capital, i.e. natural resources, the following way. It categories the natural resources into three broad types:

- Land
- Minerals
- Energy
- other natural assets

According to the SNA, must be recorded in balance sheets only the natural resources "that are subject to effective ownership and are capable of bringing economic benefits to their owners, given the existing technology, knowledge, economic opportunities, available resources and set of relative prices" [5]. As it is remarked in [2], environmental assets over which there are no ownership rights such as air, seas are not taken into account. Moreover, only the subset of timber is considered but not all forests of a country. Another example for subsoil assets is that only minerals which are known to exist with very high certitude and for which the extraction is possible and profitable today are recorded.

In natural assets are not considered resources whose growth is the result of human cultivation such as livestock, vineyards or other crops which are recorded as produced tangible capital.

Land

"5 Land consists of the ground, including the soil covering and any associated surface waters, over which ownership rights are enforced and from which economic benefits can be derived by their owners by holding or using them."[4] There are three types of land: land underlying residential buildings, land underlying non-residential buildings and other lands, including lands under cultivation, recreational lands and others. "The value of land excludes any buildings or other structures situated on it or running through it; cultivated crops, trees and animals; mineral and energy resources; non-cultivated biological resources and water resources below the ground."[4]

To separate the value of land from what is on it, the SNA indicates to subtract the replacement cost value of the buildings (obtained by the perpetual inventory method) from the value of the market of the combined land and buildings. These calculus were computed in [2].

Subsoil assets: minerals and energy "Mineral and energy resources consist of mineral and energy reserves located on or below the earth's surface that are economically exploitable, given current technology and relative prices"[4]

As it is stressed before, the SNA asks to only consider natural resources that are economically exploitable given current technologies and prices, and on which there are ownership rights. It is difficult to know to which sector they should be attributed to. Depending on the countries, subsoil assets legally belong to the owner of the ground whereas in others they belong to the government. The SNA 2008 [4] makes a clear distinction between legal and economic ownership but indicates in this specific case legal ownership should be followed and thus thus subsoil assets legally owned by the government should be recorded as assets for the government, even when they are extracted and eventually exhausted by private sector companies. When the government grants extraction rights to the private sector, a flow of rents on subsoil assets" should then be written.

As it is precised in the technical appendix of [2],the choice to attribute subsoil assets to the government when it is the legal owner is not innocuous: it potentially raises a double-counting issue. Government-owned subsoil assets exploited by private corporations are arguably capitalized in the corporations' equity prices. So they risk being counted twice in national wealth: both as government wealth (directly) and as private wealth (indirectly through equities).

In [9] it is stated that all natural assets belong to the government. I recently a few days before the date of remittance of the thesis had contradictory information. As I do not know yet which one is true, I kept my first information but will change it if necessary in an updated version of the thesis.

In the new information I was provided with, Canada makes the distinction in its balanced account on which part of the national resources is attached to which sector. It is not clear if it still owned by the government but allocated to another sector while the government still earn rents through taxes, fees and/or royalties or if there is private ownership of a subset of Canadian natural assets.

I thus consider for now that natural assets as defined by the SNA[4] are owned by the government and thus do not trigger any double counting issue.

Other natural assets and water resources

"Non-cultivated biological resources consist of animals, birds, fish and plants that yield both once-only and repeat products over which ownership rights are enforced but for which natural growth or regeneration is not under the direct control, responsibility and management of institutional units.Examples are virgin forests and fisheries within the territory of the country. Only those resources that are currently, or are likely soon to be, exploitable for economic purposes should be included. "[4] I did not take it into account in this master thesis, except for virgin forests on the top of timber for which I extrapolated the price of timber for the whole stock of forest as a first approximation.

6.2 Data from Statcan

For the monetary accounts of natural resources, only a part of energy, minerals and forests is measured and incorporated in national accounts. This part corresponds to the natural resources on which ownership rights can be claimed and from which owners can draw an economic benefit. These resources satisfy the criteria of the SNA08 [4] to define economic assets as I precised before. In this system, those assets are in the category "non-financial non-produced assets".

Concerning the energy and mineral resources, are recorded only the part of the stock of Canada whose existence is known with a high certitude level and whose extraction can be profitable today. Concerning timber, the proportion of measured forests is the one from which the wood can be harvested and tradeable in a reasonable amount of time.

It is thus important to specify that there we can consider two set of stocks: the global set of resources which for instance recover all the forest or all the minerals that are known to exist, which I will soberly name "set 1", and the marketable subset considered in the data which will be named "set 2". Apart from forests for which the World Bank provides estimates of the area of all forests not depending on their economic benefits, and thus a physical value of set 1, we only have access to set 2 in our computations. The case of timber and forest will be detailed in another paragraph as it allows us to compare the visibility we can have on these two sets. However, although for forest and timber the distinction between the two sets can be considered as due to a choice of attribution of some forest for timber and the rest for direct "cultural benefits", protection of "the lungs of the planet", or protection of the habitat of animals and thus not valued in national accounts, there is no such distinction for subsoil assets (energy plus minerals) and the data we have could be, even if it is set 2, an approximation of set 1 (modulo discoveries that would then happen simultaneously in set 1 and set 2).

Physical stocks

It is first interesting to ask the question "what are the possible meanings of an increase or a decrease in capital natural, regarded as physical accounts and thus ignoring the possible price effects?". Indeed, with classic manufactured capital, an increase in capital can only come from production and thus investment, and a decrease in capital can only come for depletion of the capital. With natural capital it is different for several reasons. The first one is obviously that it cannot be manufactured. Thus, an increase of the physical stock of a resource can come from

1. The discovery of new resources
2. The reevaluation of the stock, that could have been misestimated before
3. Growth of the resource stock (for instance forest reproduction)
4. Addition from the total resources set to the economically valued set.

and a decrease of the physical stock of a resource can come from

1. The depletion of the stock directly due to extraction
2. The depletion of the stock due to natural catastrophies
3. The depletion of the stock due to pollution or other negative externalities from any human activity
4. The reevaluation of the stock, that could have been misestimated before
5. Withdrawal from economically valued resources set.

These variations of the physical stocks are coupled, when the resources are valued, with price effects.

Methods of valuation

The first step of estimation of the flow of income is to calculate the income coming from the extraction of the current year. This income, or rent of the resource, is equal to the total revenues from sales from which is subtracted the costs of extraction. These costs gather exploitation costs, labour force, use of capital such as depreciation of the machinery. Taxes, fees and other costs not directly linked to the extraction process are not subtracted.

$$RessourceRent_{I,t} = TR_t - C_t - (r_{i,t}K_t + \delta_t)$$

- TR_t is the total revenue from extraction of the resource at time t
- C_t: annual extraction costs at time t
- $r_{i,t}K$: opportunity cost of investing in capital for extraction at time t
- δ_t depletion of capital stock K at time t

In theory, this is the correct method of estimating the resource rent which should be net of all extraction costs, including capital costs, to accurately represent the return to the subsoil asset. The Concepts, Sources and Methods of the Canadian System of Environmental and Resource Accounts [?] however raises the uncertainty about the term $r_i K$ of return of produced capital. Indeed, the resource rent sometimes becomes negative after the deduction of this term for small resources such as gold. It could make this relation inappropriate but we can still use it as a lower bound of the value of the resource rent. An upper bound could then be

$$ResourceRent_{II,t} = TR_t - C_t - \delta_t$$

.

Using it allows to address the uncertainty of the return to capital term by giving an interval of values. The "true" rent of the resource lies between the two values. Practically, the two values are not so different for the aggregation of all resources taken into account in the data.

To estimate the resource stock value, at time t, we just have to deduce from the resource rents the rent of a unit of resource by dividing the rent by the quantity of resource sold and to multiply it by the total quantity of the known exploitable stock.

$$NetPrice_{I,t} = \frac{ResourceRent_{I,t}}{Q_t} S_t = \frac{TR_t - C_t - (r_{ti,t} K_t + \delta_t)}{Q_t} S_t$$

with

- Q_t: physical quantity extracted this year at time t
- S_t total physical stock at time t

$$NetPrice_{II,t} = \frac{ResourceRent_{II,t}}{Q_t} S_t = \frac{TR_t - C_t - \delta_t}{Q_t} S_t$$

As for the resource rents, the "true" rent of the resource should lie between the two values which give an upper and a lower bounds.

However estimating the market value of the resource asset stock is complicated by the fact that the extraction of some resources will lie on a long amount of time. The market value of the stock could then be given by a discounted value of the future stream of resource rent realizable from the stock as income earned from extraction tomorrow is worth less than that earned today. It would then be:

$$PresentValue_t = \sum_{\tau=1}^{T} \frac{ResourceRent_{I,t}}{(1+r_g)^{\tau}}$$

with r_g the government bond rate.

This method of present value is based on the fact that the extracted quantity of resource and the rent from extraction will stay constant the following years until the reserves are extincted. Two limits of this approach are thus this assumption of constant extraction quantity along the lifetime of the resource and the assumption that the difference between revenues from extraction and extraction costs will remain constant over the lifetime of the resource. Indeed, the price of a natural asset has often a bigger variance than the extraction costs, labour force costs and capital depreciation costs.

6.3 Data from World Bank

The World Bank provides an international and very diversified database, and especially provides data on depletion rates of nature, rents from nature, damages due to CO2 or other greenhouse effect gas. These values where used by E. B. Barbier in [3] to built his adjusted net saving rates s^* and depletion rates of nature n^*. I use this database both to complete when needed the data I got from Statistics Canada and to compute the the values of s^* and n^* taking into account on the top of natural depletion the social cost of greenhouse effect gas as a depletion of natural capital.

6.4 Building 'ex post' data

Canada environmental accounts show estimates for opening and closing stocks of subsoil assets and timber in each year, plus the volume changes that occurred during the year. Volume changes resulting from reserve discoveries, additions and depletion are recorded in the physical accounts. To build 'ex post' stocks, I consider that all the discoveries and additions to stock already existed and thus add to the last census of a resource (on which were thus already added all the previous discoveries) all the depletion between the date on which I want my 'ex post' stock and the last date of census:

$$Stock_{expost,t} = Stock_{exante,2014} + \sum_{\tau=t}^{2014} depletion_{\tau}$$

It perfectly follows the opposition between Figure 1 and Figure 2 in Section 3.

7 Natural Capital of Canada 1970-2013

I will extrapolate in this section the value of a unit of timber (ha) to all forests which broadly multiply its value by 2.8 and will discuss in another section how the distinction between timber and forest is interesting.

7.1 Dynamics and decomposition of natural capital

We observe here the ratio of natural wealth using the first method of valuation $NetPrice_I$ described in [9], extrapolating the value of timber to forests on adjusted net national income, i.e. net national income adjusted for depreciation of natural capital (forests, minerals, energy). $NetPrice_I I$ follows approximately the same path with just a little higher values.

Figure 4 shows that natural wealth-income ratios have, 'ex ante', increased between 1970 and 1979 from about 300% to 460% to lower abruptly to 240% and slowly increasing on the 1985-2007 period to reach 320% for increasing a lot and reaching a peak above 600% in 2008 and finishes around 500% in 2011.

From a nature of wealth point of view, Lands seems, as its volume is by definition constant, to have a steadily rising trend and so rising price index along all the considered period of time. However, energy, minerals and forests have much more chaotic variations. Minerals almost always seem to be the largest part of the three remaining resources, especially in the 2000s. Its value however declined a lot over the periods of 1983-1989 from 120% to 11%, and to recover higher values between 60% and 90% of adjusted net national income to reach 285% in 2008 and remain high later. It is notable that energy reached also very low values on the period 1986-1999 between 12% and 36% of adjusted net national income.

It is interesting to notice that in 1978, the three resources had very equivalent values. It change a lot to finish in 2011 at 24%, 229%, and 97% respectively for forests, minerals and energy.

Let us now compare Figure 4 with Figure 5, the 'ex post' counterpart of Figure 4. I recall that it thus takes into account the stocks of discoveries over the period as already existent in 1970 even if we did not know. The price of a unit of unknown stock has been as a first approximation put at the same level as a unit of already known stock considered in the 'ex ante' case. Consequently, the stocks of resources can only diminish, and any rise on the value of natural stocks is thus due to a price effect or a lowering adjusted net national income. However, adjusted net national income is almost always increasing on the period of 1970-2011. Hence, any rise can be considered as a price effect.

As a whole, natural assets represents between 1970 and 1980 between 800% and 1000% of adjusted net national income. It diminishes a lot from about 950%in 1980 to about 250% in 1987. It later steadily increases from this value to almost 500% in 2011. We will see next the decomposition between price and volume effect to understand exactly of much of the whole resources were depleted in about 40 years, as here the ratio is almost divided by two on the period.

Concerning the different resources, we can first remark that there is no change in forests nor lands. Indeed, no new discoveries of forests or land were made along the period, and Figure 18 shows that the forest area have only been declining on the considered period, and no natural growth either.

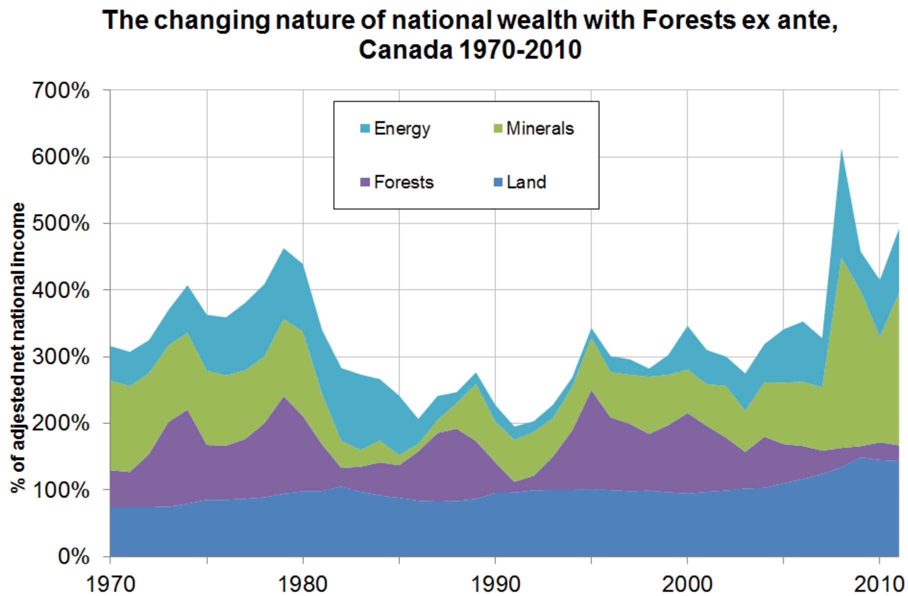

Figure 4: NaturalWealth= Energy + Minerals + Lands + Forests

It is also interesting to remark that the most valuable resource on the period is globally the energy whereas it was minerals 'ex ante'.

Moreover, the distinction between 'ex ante' and 'ex post' shows completely different dynamics for the value of natural capital, both by resource and as a whole. It shows that from the point of view of today, we diminished our natural wealth by two whereas it is not visible from the 'ex ante' viewpoint on Figure 4 where natural capital even seems to have increased on the 1970-2011 period. The tremendous importance of the numbers shows the importance of that fourth difference between natural and manufactured capital as for a change of point of view of only 40 years maximum, it changes the entire shape and dynamics of wealth.

We will decompose the trend of each of these resources next to understand if we really consumed half of our resources, or in which measure the price effect affects these dynamics.

7.2 Price and Volume effect

To reach a better understanding of the division by two of the value of natural resources (land omitted as the quantity of land does not change), I distinguished the volume effect (evolution of the quantity of the resource in physical units) and the price effect (evolution of the price of a unit of resource net of inflation and GDP price index). It gives for all t:

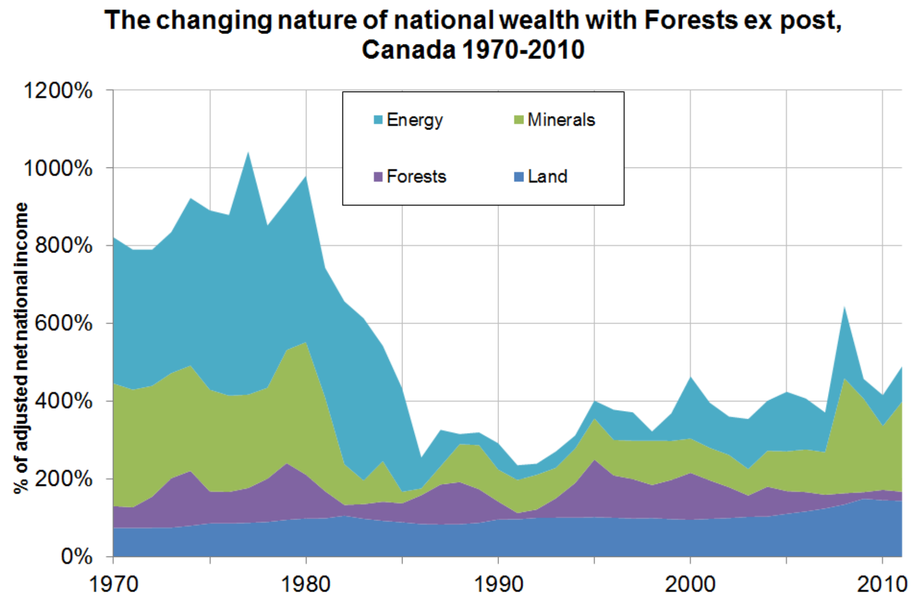

Figure 5: NaturalWealth= Energy + Minerals + Lands + Forests

$$\frac{\beta_{n,t}}{\beta_{n,1970}} = \frac{V_{n,t}}{V_{n,1970}} \frac{p_{n,t}}{\frac{Y_{n,t}}{Y_{n,1970}}}$$

with

- $\beta_{n,t} = \frac{W_{n,t}}{Y_{n,t}}$ the natural wealth-income ratio at time t
- $V_{n,t}$ the aggregate volume of natural resource in physical units
- $p_{n,t}$ the price index of natural assets normalized to 1 in 1970.

Figures 6, 7 and 8 give the evolution of the three ratios for each resource type separately (forests, minerals and energy) as the aggregation in volume for each type is more direct. Indeed, all minerals are measured in tons, and all different energy sources have Joule equivalents. Figure 11 gives the evolution of the aggregation of the three weighted by the share of natural resources they represented in 1970.

Figure 6 indicates that almost the whole variation of forests values are due to price effect. However Figure 18 shows more clearly that the volume effect is negative with a loss of about 0.6% of global area between 1970 and 2013.

The depreciation of minerals seems to be steady between 1975 and 2014 with a decline of 23% of minerals on the given period. The rest of variations are due to price effects (Figure 7).

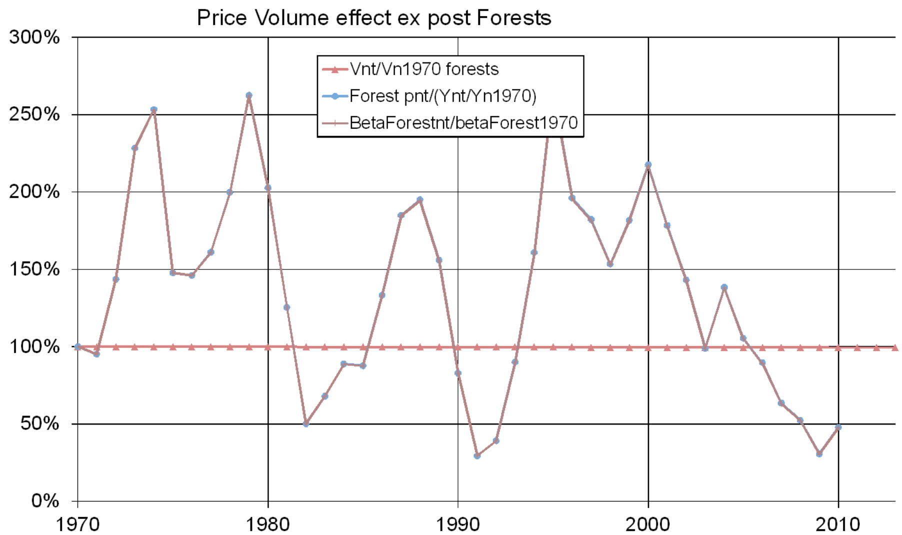

Figure 6: Decomposition of price and volume effects of Forests in Canada 1970-2013 ex post

Figure 8 shows that more than half of energy resources were depleted on the period 1970-2013 in Canada. The consumption of the energy resources seems to intensify with time. Figure 9 shows the decomposition of main energy resources in Canada on the period 1961-2013 in Joules. While crude bitumen, coal and lignite reserves were almost not depleted, the quantity of oil was more than divided by 4 on the considered period, and so do natural gas reserves.

On a whole, Figure 10 shows that, without considering Lands as its volume cannot change (no new land discoveries or disappearance under water according to the World Bank Data base: the surface of lands has remained the same since 1961, as far as the database goes back), more than 35% of natural resources were depleted on the period of 1970-2013. Figures 6, 7, 8 and 9 allows to see that this loss is in majority due to the consumption of energy, then minerals and lastly forest depletion. On a whole, depletion of natural resources, influenced as we saw by the acceleration of energy resources consumption, is fastening on the period as the volume line is concave.

The figures also show that the prices of minerals, energy and timber have a tendency to be very unstable in comparison with the general price index.

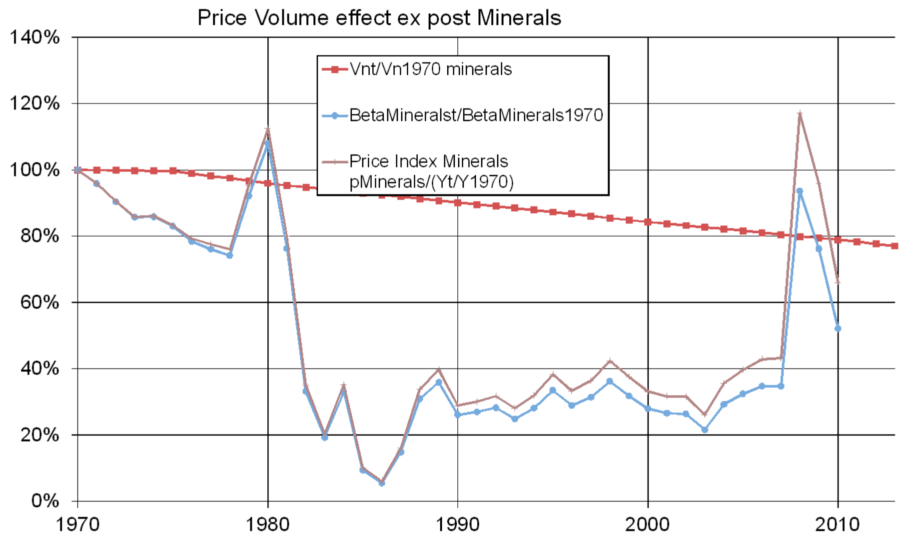

Figure 7: Decomposition of price and volume effects of Minerals in Canada 1970-2013 ex post

8 Wealth Income ratios and saving rates of Canada from 1970 to 2011

8.1 The addition of natural capital to national wealth

In Capital is Back[2], Thomas Piketty and Gabriel Zucman established the evolution of wealth-income ratio for eight of the top developed economies. I use the previous valuation of nature to add it to national wealth, and adjust net national income for the depletion of natural resources. Figure 11 and 12 show the evolution of this new wealth-income ratio 'ex ante' and 'ex post' and compare it with the results of [2]. Their ratio were already taking into account Land, so it is not added here.

I recall that I consider for now that natural assets as defined by the SNA[4] are owned by the government and thus do not trigger any double counting issue, as it is specified p28 of the Canadian notice [9] .

It is first interesting to notice in figure 11 that natural wealth represent often almost half of total wealth. Where the wealth-income ratios of Canada evolved between 280% and 400% on the considered period, it now evolves between 400% and 900%. Moreover, as the prices of resources are very unstable, the line is

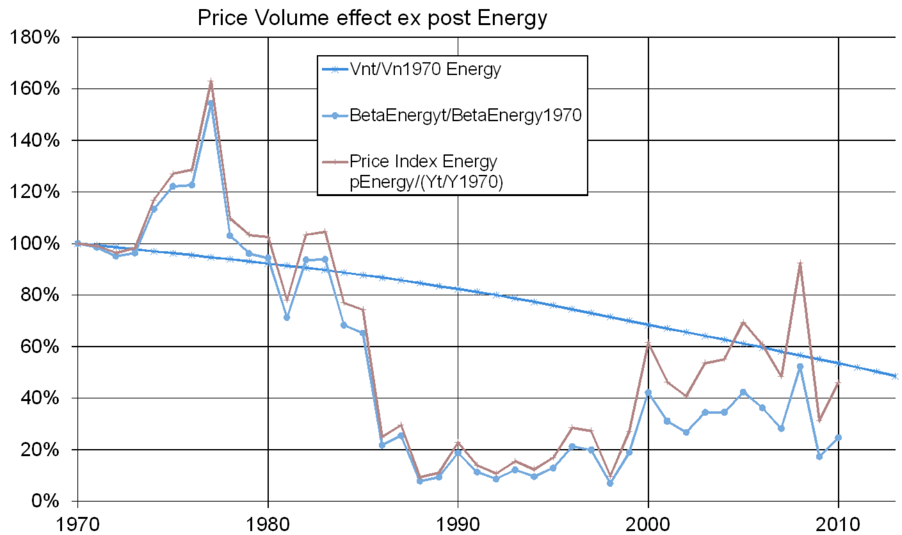

Figure 8: Decomposition of price and volume effects of Energy in Canada 1970-2013 ex post

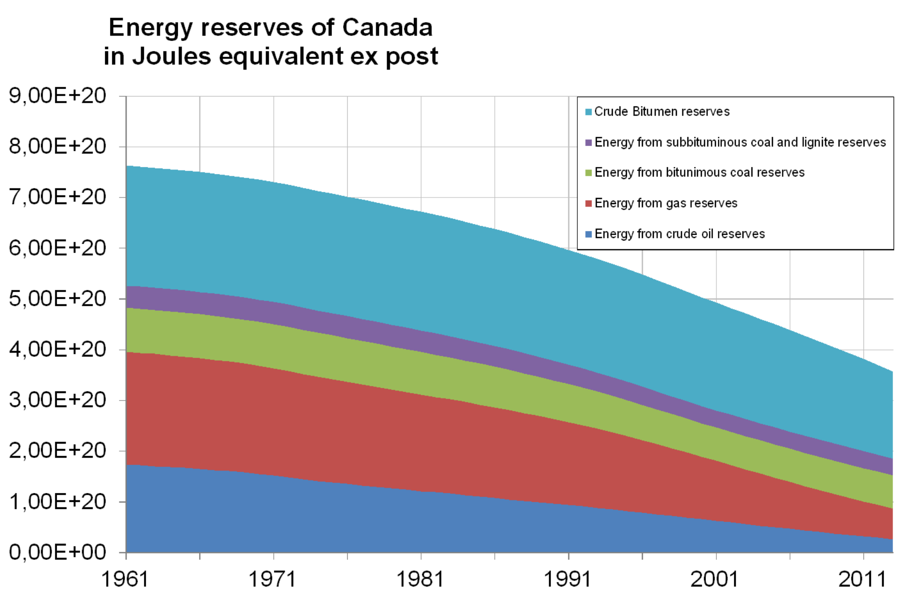

Figure 9: Energy reserves of Canada in energy units Canada 1961-2013 ex post

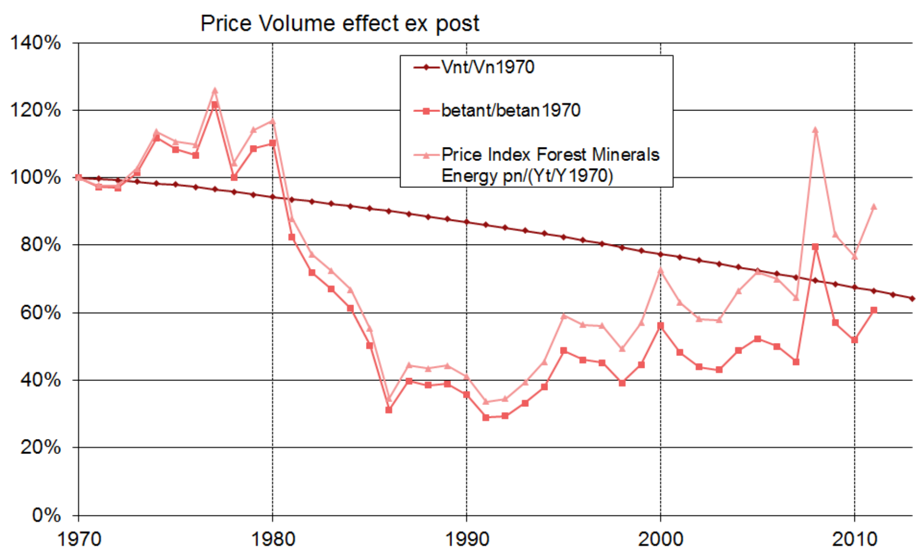

Figure 10: Decomposition of price and volume effects of natural resources in Canada 1970-2013 ex post

very irregular. It declines from 700% to 400% between 1980 and 1990 before gradually increasing until reaching values above 800%. Figure 10 shows the evolution of prices index of nature which can partly explains this evolution, coupled with depletion and discoveries of resources.

Figure 12, the 'ex post' version of Figure 11, shows very different dynamics and numbers, especially before 1990. Indeed, the ratio is first remaining between 1970 and 1980 in an interval of 1050%-1200%, before plummeting from 1100% to 500% in 1986. As stocks are non-increasing in this figure, any increase of the ratio has to be a price effect.

We can remark that the physical trend of natural resources does not follow what Hartwick [17] prescribed in his article "Intergenerational Equity and the Investing of Rents from Exhaustible Resources". Indeed, an ethical consumption of resources (meaning consumption in the general sense per capita constant, intergenerational equity) with a finite stock of non renewable resources demands the flow of resources extracted to asymptotically approach zero as time tends to infinity. The trend on Figure 10 shows that it is not the case here. (the flow, derivative of the stock does not seem to converge to zero).

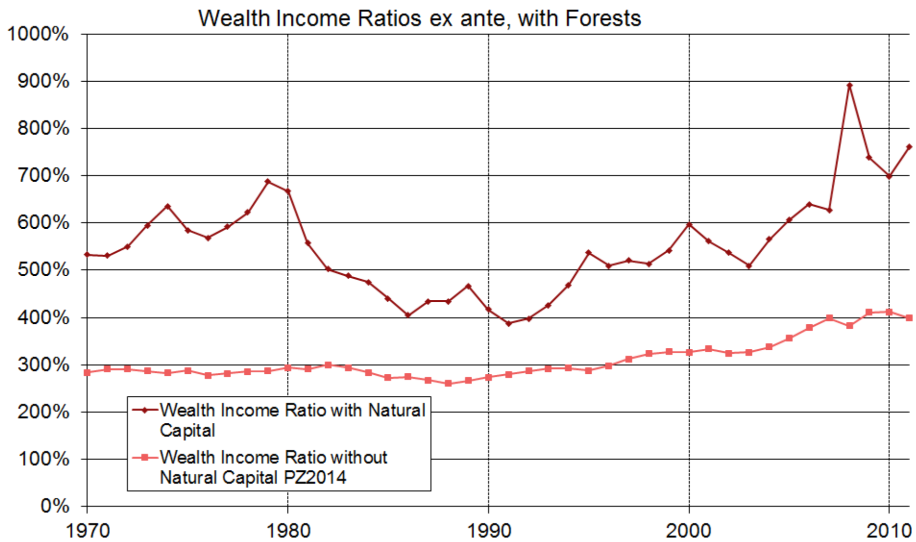

Figure 11: Total Wealth-Adjusted Net National Income ratio of Canada from 1970 to 2011 ex ante.

As the difference between ratios and the decomposition of natural wealth 'ex ante' and 'ex post' (Figures 4, 5, 11, 12) is significant, it confirms that while we thought that we behave 'ex ante' as Figure 4 or11 show, we really were behaving as Figure 5 or 12 display. The 'ex post' figures show the real evolution of Canadian wealth, which is very different from the one seen from the 'ex ante' viewpoint, punctuated by discoveries of new stocks of resources. This shows how different wealth can be seen after 40 years of knowledge and discoveries of very studied resources as timber, minerals and energy occupy a very central role in industry. If the dynamics of natural capital is so different between the two viewpoints for those resources carefully managed by the government and industries, we can assume that the evolution of natural wealth will be all the more different after valuing other parts of nature and natural services as [1] that are not directly involved in the management of production. The message is that as we behave 'ex ante', we do not realize our real impact on nature as we do not know nature and history is constantly punctuated by new discoveries altering the values of natural assets from the point of view of human activities. It thus gives an important place to the fourth difference I added between natural and manufactured capital in section 3 and its impact, and emphasizes the importance of the implementation of precautionary principles. Furthermore, as the three differences stated by E. B. Barbier in [1] had an impact on the way he constructed his valuation framework, the fourth difference should

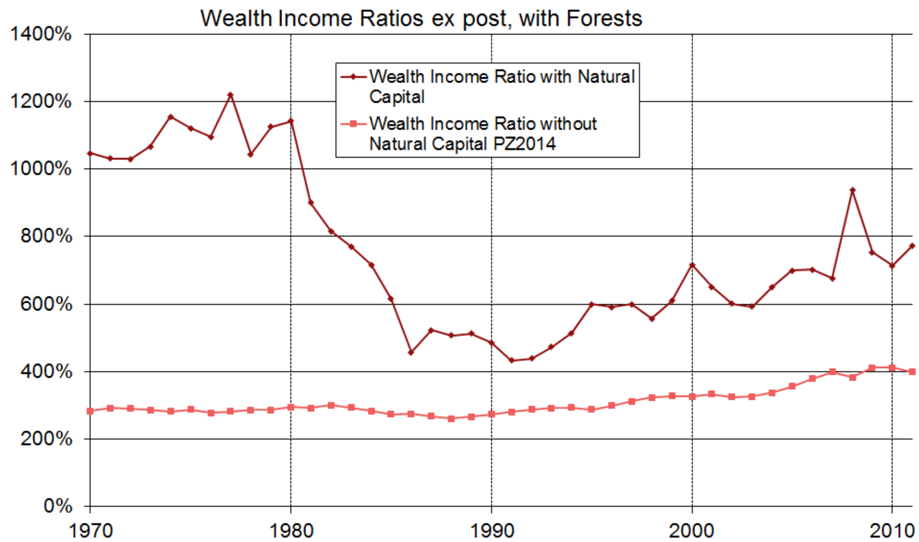

Figure 12: Total Wealth-Adjusted Net National Income ratio of Canada from 1970 to 2011 ex post.

have an impact too.

8.2 Adjusted net saving rates

In his observation of s^* and n^* for the eight richest countries treated in [2], E. B. Barbier in [3] observes that s_t^* and n_y^* had been converging. "The long-run fall in the adjusted net savings rate indicates that there is less accumulation of other forms of capital each year to compensate for ongoing natural capital depreciation" he explains.

I adapted his results using the World Bank database as he did, taking into account in the depreciation of natural capital the social cost attributed to CO2 emission, particles emissions, and other greenhouse effect emissions damages such as HFC, PFC and SF6. This leads to higher n^* and lower s^*.

n^* is here the sum of net forest, energy, mineral depletion plus the social cost of greenhouse gas that can be considered as a depletion of nature too. s^* is the adjusted net saving rate, i.e. gross national savings less the value of consumption of fixed capital and natural depletion n^*. n^* and s^* are expressed in percentage of the adjusted net national income.

Figure 13 depicts the estimates of s^* and n^* for Canada between 1970 and 2014. The adjusted net savings rate is very unstable and globally non-increasing, reaching negative values in the beginning of the nineties and in 2010, which

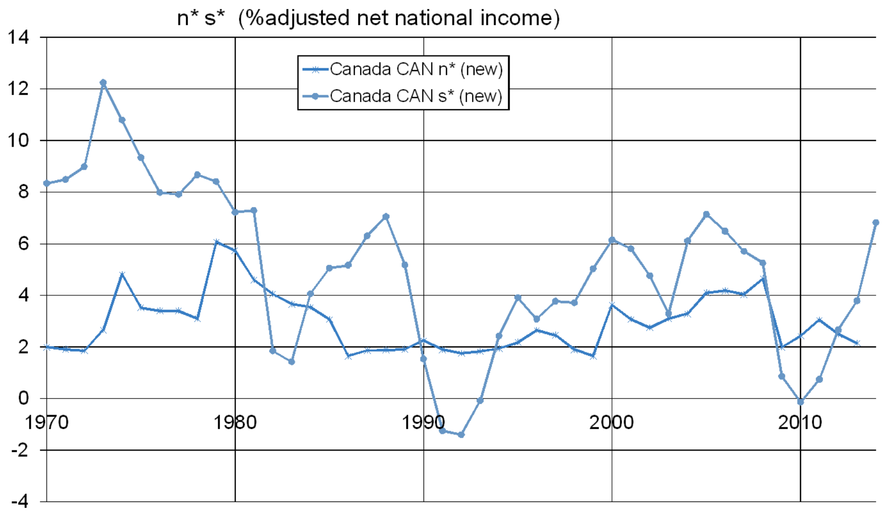

Figure 13: s* and n* Canada 1970-2014

means that those years, investment did not compensate for depletion of natural capital in Canada. Natural depletion seem always between 2 and 6 percent of adjusted net national income with no clear trend.

Figure 14 depicts the estimates of s^* and n^* averaged across eight rich countries between 1970 and 2014. The trend is not modified a lot in comparison with the results of [3]:natural capital depreciation has remained between 1 and 2 percent of adjusted net national income on the considered period. The adjusted net savings rate declined a lot during the four and a half decades, from about 13% in the early 70s to about 3% in the beginning of the 2010s. This fall over 45 years indicates, as concluded Barbier in his article, that there is less and less accumulation of other forms of capital each year to compensate for ongoing natural capital depreciation.

9 Timber versus Forest

I would like to end with a very significant comparison between what is visible at first sight ('ex ante') and what we see now. As precised in the SNA at first sight, forest should not be valued in economics accounts as it does not provide direct benefits to its owner: only a part of it, timber, is recorded. However, our discoveries about the social cost of CO2 and the fact that forest contribute to CO2 sequestration (without talking about the protection of animals habitats, food, climate and water regulation, groundwater recharge, pollination, beauty, etc), makes us want to consider, 'ex post', the evolution of the whole population

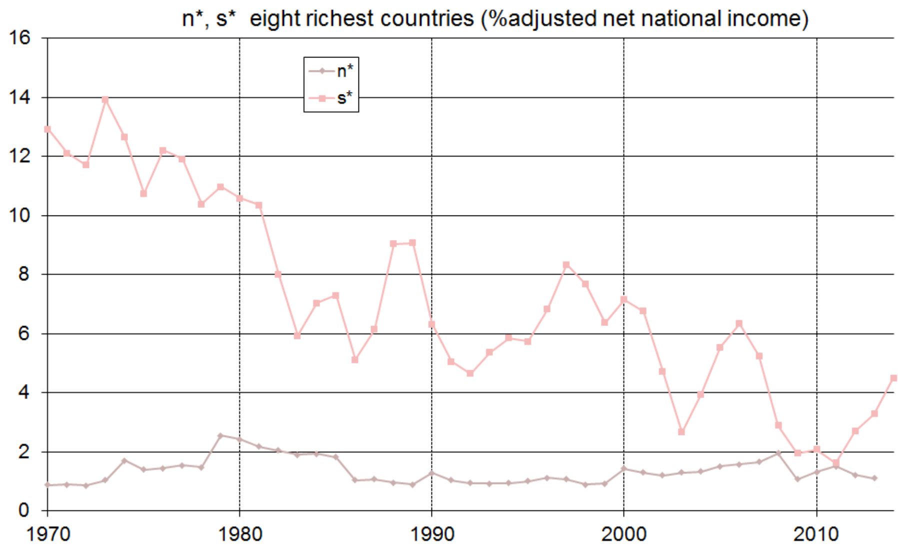

Figure 14: s* and n* eight high-income countries 1970-2014: The eight countries are the United States, Japan, Germany, France, United Kingdom, Italy, Canada and Australia.

of forests, for example valued for carbon sequestration.

As stated in The Changing Wealth of Nations, Measuring Sustainable Development in the New Millennium from the World Bank[7], Kankhauser [6] built in 1995 a range of estimates of the social cost of marginal carbon emissions, and evaluated at (1995) \$20 per ton of carbon.

The evolution of Timber in area units is increasing in function of time, as additions to the stocks and natural growth are more important than industrial removal, natural depletion, or fires, whereas the whole population of forests is decreasing in physical units, as shown on these figures.

The notable difference of both physical and price trends shows the strong distinction between between the two viewpoints (Figure 15 and 16 on the one side and Figure 17 and 18 on the other side) . Indeed, if we had not valued trees for their capacity of sequestrating CO2, and we would not have visualized the loss of capital due to deforestation because we would not had got interested into the whole forest. This difference is however directly visible on graphs

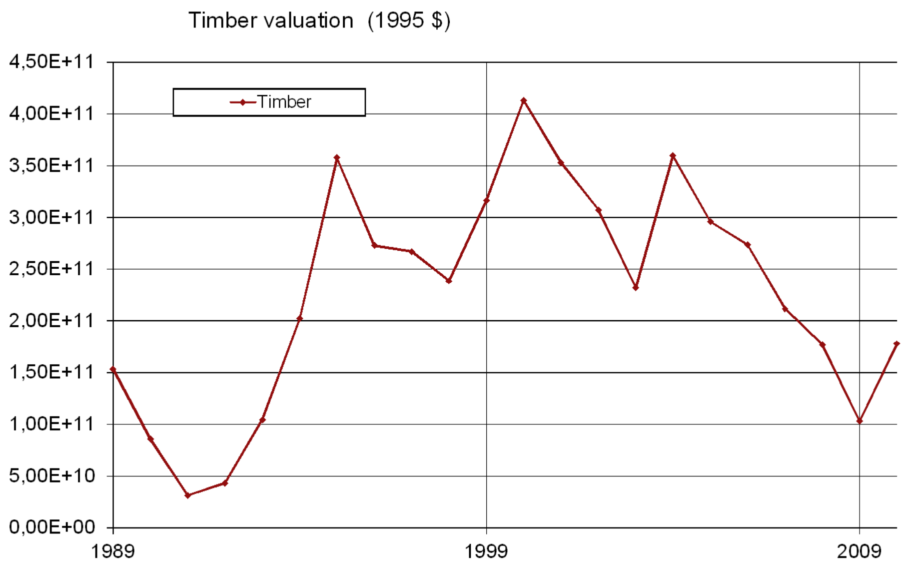

Figure 15: Timber valuation: market Value, Canada

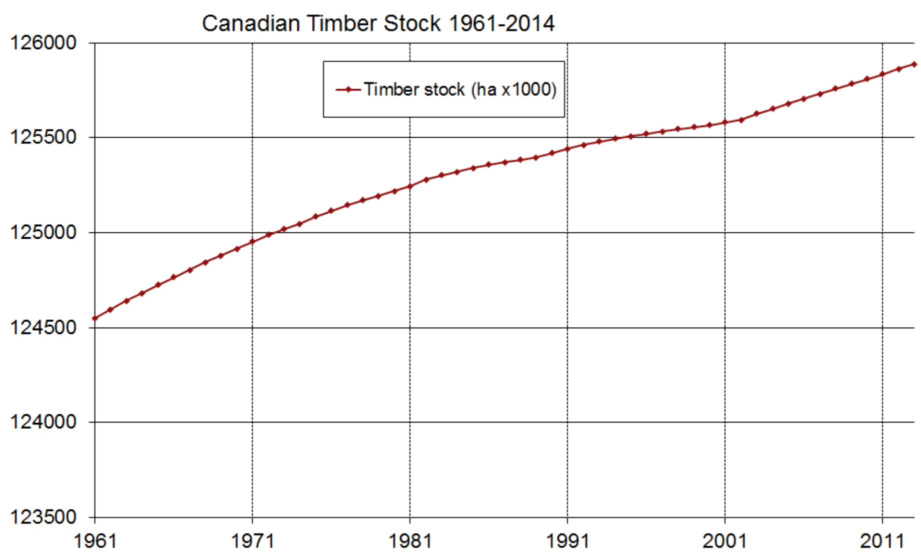

Figure 16: Timber stock in ha x 1000, Canada

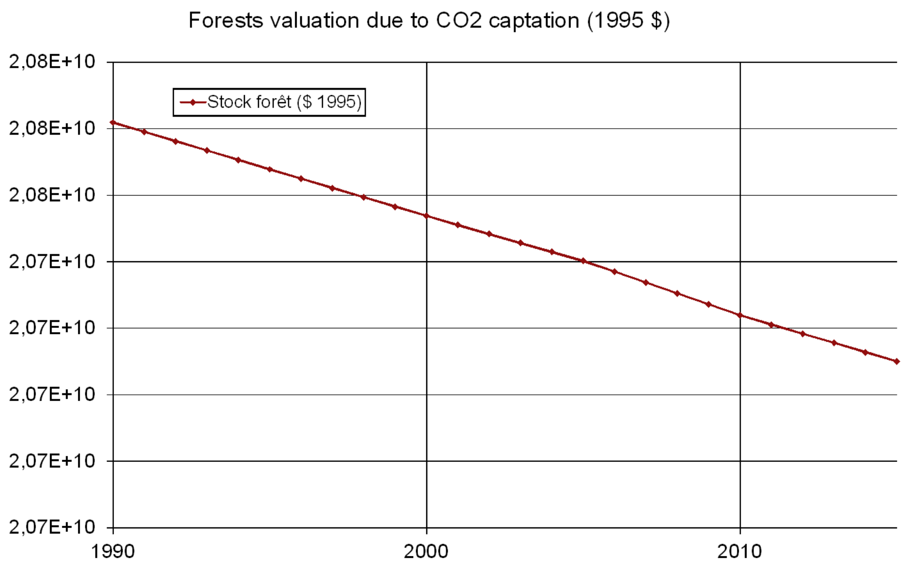

Figure 17: Forest Valuation for Carbon Sequestration, Canada

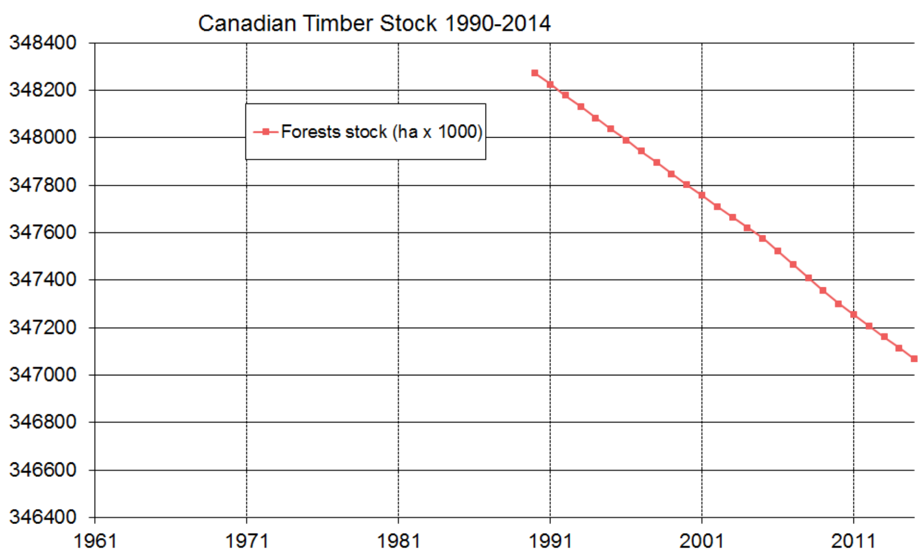

Figure 18: Forest stock in ha x 1000, Canada

in physical units, which shows their importance, but not alone: physical and scientific description should be attached to it as described in the first chapter to have a better understanding of the benefits drawn from forest, with or without monetary valuation.

The lesson of this comparison is that the way of valuing a resource can also change the set of resource considered, and thus does not allow to seize the real impact of an economy on nature.

Here the comparison gives, even if the trends change, a higher value for an ha of timber in comparison with an ha of forest valued for carbon sequestration. However, Lescuyer [16](2007) valued climate regulation by tropical forest in Cameroon at a higher price per hectar than for the timber value (560 against 842 $). In that case the difference between the two viewpoints ex ante where we only know for timber value and thus only value the timber set and ex post where we value the whole forests for climate regulation would have been enormous: if as in Canada timber stocks were increasing whereas forests stocks decreasing, the economy would have ignored its real impact on its wealth. This one last time gives its full relevance to the fourth difference between natural capital and manufacture capital and consequently to precautionary policies.

10 Conclusion

As it is difficult to predict future discoveries, it seems difficult to put a price on nature taking into account the very fact that we do not know everything about it nor every services it provides. The comparison of the two viewpoints 'ex ante' and 'ex post' where very fruitful on bringing to light this point. Consequently, the wisest way to put a value on nature to reflect both its stock but also its health and its description would be to organize the most complete physical census and scientific description as possible. As we saw for the case of Canada, only physical data allowed us to observe the depletion of 35% of natural reserves between 1970 and 2013, the price index of natural resources being to much volatile.

In business decision, we saw that a relevant way to tackle this problem of valuation is to put on nature the price of its replacement. In another way, a compensation law "n2016-1087 du 8 août 2016 pour la reconquête de la biodiversité, de la nature et des paysages "is tested in France today that in a way put the price of replacement on nature: any destruction should be replaced.This law has an impact on the business level but could change the way our production system interacts with nature, and thus change significantly the trends of natural stocks. It does not solve the problem of valuation of nature but gives it indirectly a price that incorporates the "unknown" dimension of nature that I described as the fourth difference between the two types of capital.

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